Chapter 1
Introduction to Part I

For hundreds of thousands of years human beings lived without using any particular means of transportation. When they had to move an object, they simply lifted and carried it, if they were strong enough. If the object was too heavy, they arranged to drag it. It is likely that occasionally branches or other round objects were slipped under the load to reduce friction, but no evidence of this practice remains.

With the Neolithic revolution the need for transportation greatly increased at the same time that the practice of taming animals opened new perspectives. The development of agriculture created the need of transporting seeds to the field and crops back to the homestead. The number of objects that were considered important and necessary for humans to carry with them increased as a result of the new needs of village life.

Sleighs were used in Northern Europe before 5000 B.C., and their use in other places at that time can be inferred. Sleighs and sledges can actually be used for transportation not only on snow and ice but also on grassland (American Indians used the *travois* well into the nineteenth century), deserts and sometimes even on rock.

It is impossible to state when a sledge was mounted for the first time on a pair of wheels or who instigated this technical revolution. Ancient wheels were made primarily of wood, so that little direct archeological evidence would remain.

The potter's wheel was introduced about 3500 B.C. to produce pots with axial symmetry. The use of the potter's wheel can be inferred from the marks left on pots made with it. The supporting wheel for vehicles is thought to have originated at about the same time.

The most ancient evidence of a wheeled vehicle is a pictogram on a tablet from the Inanna temple in Erech, Mesopotamia. This document dates back to slightly later than 3500 B.C., and includes a small sketch of a cart with four wheels, together with a sketch of a sledge (Fig. 1.1a).

The vehicle shown in Fig. 1.1b has two features typical of all vehicles for more than a 1000 years: The wheels are discs made from three planks of wood, and the animals are harnessed to a central shaft.

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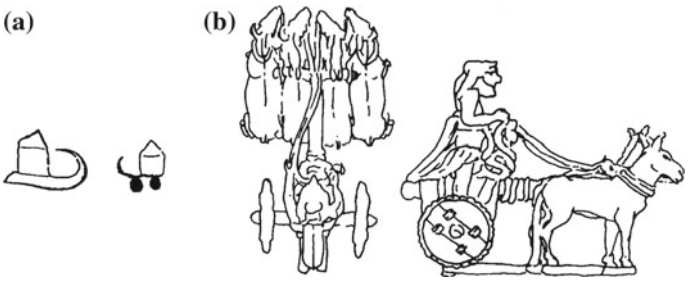

Fig. 1.1 **a** Pictogram on a tablet from the Inanna temple in Erech, Mesopotamia. The document dates back to slightly later than 3500 B.C., and includes a small sketch of a cart with four wheels, together with that of a sledge. **b** Copper model of a war chariot, driven by four onagers, found in the tomb of Tell Agrab, from the third millennium B.C. (from Genta and Morello 2009)

This uniformity of wheel types and driving systems, particularly when compared with the great variety of vehicle structures, has led to the opinion that the wheel was *invented*, or better, developed, in a specific place and then started a slow diffusion throughout the ancient world. In various places where the new vehicle was introduced, the local type of sleigh was adapted to it using the standard wheels and harness.

Where wheeled vehicles were first developed is not known, but it can be inferred that it was in Southern Mesopotamia, where the wheel was definitely used about 3500 B.C. The spread of the wheel was quite slow. Evidence of its use dates from 3000 B.C. in Elam and Assyria, 2500 B.C. in Central Asia and the Indus Valley, 2250 B.C. in Northern Mesopotamia, 2000 B.C. in Southern Russia and Crete, 1800 B.C. in Anatolia, 1600 B.C. in Egypt and Palestine, 1500 B.C. in Greece and Georgia, 1300 B.C. in China and about 1000 B.C. in Northern Italy. Some centuries later it reached Northern Europe.

It is impossible to know from ancient pictures whether the axle turned along with the wheels or was stationary. The fact that the central hole of the wheel disc was round has little meaning as a circular hole can also be explained by the ease of construction. It is likely that both solutions were used, as it is the case with people who use these primitive technologies today (Fig. 1.2).

It is, however, likely that the wheel did not derive from the roller: The types of wheels used would rule that out, and it is likely that, in the mind of the ancient wheel maker, the wheel and the roller had little in common.

As previously noted, only after animals were tamed could wheeled vehicles be propelled in a proper way. In Mesopotamia both transportation vehicles and war chariots were pulled by onagers. Oxen were doubtless used for transportation as well.

The spoked wheel, which appeared about 2000 B.C., accompanied the use of horses to drive war chariots. It is not known where horses were first tamed and used for that purpose, but the scarce archeological evidence indicates that it likely happened in north-east Persia, and that from that region the use of horses spread throughout the ancient world, from China to Egypt and Europe.

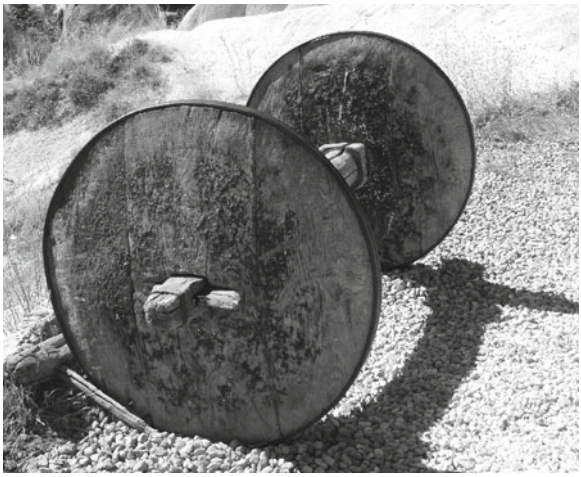

Fig. 1.2 Cart axle with two wheels dating back to the mid-twentieth century. Except for the iron tire, the structure with a disc made of three planks is the same as that of prehistorical wheels. The axle turns together with the wheels (picture taken in Urchisar, Turkey, in 2011)

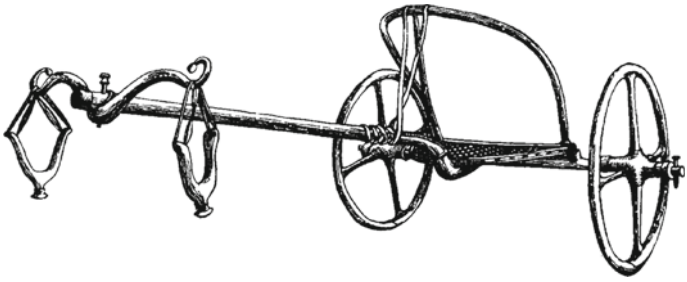

Fig. 1.3 Egyptian war chariot found in a tomb near Tebe (fifteenth century B.C., from Genta and Morello 2009)

The structure of an Egyptian chariot of the fifteenth century B.C. is shown in Fig. 1.3. It represents without any doubt the best state of the art of its times, one that remained unchanged for centuries.

The progress from the Sumerian vehicle shown in Fig. 1.1b is great, and if the greater power of the two horses compared with that of the onagers is considered, it is easy to understand why some historians ascribed to the use of this weapon the expansion of the Hittites in Anatolia, the Achaei in Greece and the Hyksos, who in the eighteenth century B.C. invaded Egypt, teaching the new technology to the Egyptians.

Chariots became obsolete as military vehicles when the knowledge of riding became widespread. Donkeys were used as pack animals and for human transportation in the third millennium B.C. and horses were surely used in the same way, but

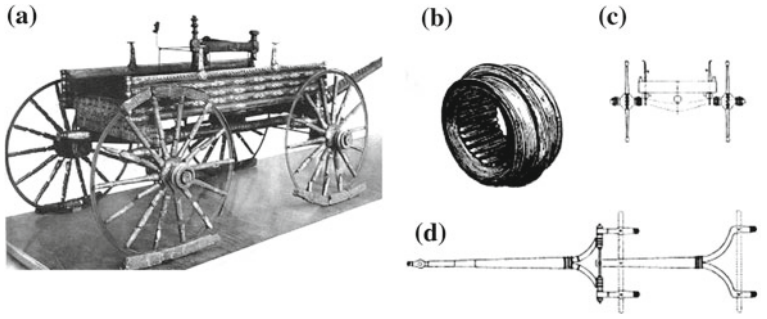

Fig. 1.4 Celtic carriage from the first century B.C. found near Dejbjerg: **a** picture, **b** wooden roller bearings in the wheel hub, **c** *cross section*, **d** *top view* (from Genta and Morello 2009)

only at the beginning of the first millennium B.C. the art of riding was developed enough and mounted warriors started to substitute chariots in the conflicts in the Middle East, North Africa and Europe. By the fourth century B.C. the armored cavalry introduced by Alexander the Great had a winning hand on most battlefields.

In Europe only the Celtic tribes continued to use war chariots, which were first carried north of the Alps by the Etruscans. Celtic wheelwrights learned the art of building wheeled vehicles and made significant progress.

The remains of the wagon found at Dejbjerg are shown in Fig. 1.4a. It is the first example of a wagon with steering on the front axle, but it can be considered as an articulated vehicle made by two chariots. It is, however, unlikely that this solution was actually used for transportation; it looks more an insulated example for ceremonial (burial) purposes. At any rate it incorporated other interesting features, such as the wooden roller bearings in the hubs.

When the military pressure was over, the progress of vehicles on wheels slowed down. Greeks and Romans used chariots only for ceremonies or races, while transportation on wheeled vehicles was hampered by the lack of suitable roads. The transportation vehicles of roman times, both in the form of two wheeled carts (the *birota*, with a payload of about 60 kg), or wagons (carrying up to 500 kg), were no more advanced than those of more ancient times, and above all wagons had neither steering nor suspensions. The Assyrian wagons of the third millennium B.C. remained practically unchanged for thousands of years.

The increase of commerce and the new needs of personal mobility which took place in the last centuries of the Middle Ages continued at a greater pace in the following period. A new confidence in progress and in the possibilities of technology led to try new experiments and to refine existing machines. It is believed that the steering of the front axle of four-wheeled wagons dates back to that period, even if some scholars think that this important innovation is older. The first coaches with the body suspended on belts or chains date from the beginning of the fifteenth century, but the innovation did not spread out fast. In 1665 steel springs were introduced for the suspension of vehicles, but only at the beginning of nineteenth century this

practice became general and it was possible to suspend the heavier vehicles on steel springs.

At any rate, in spite of all the progress in the means of transportation, journeys on land were still made on foot or on horseback (more often on the back of donkeys or mules). Still in 1550, in Paris only five coaches were reported, including that used by the queen.

The widespread use of prime movers like the water wheel and the windmill lead some visionaries to forecast the construction of self-propelled wheeled vehicles, even if there was no practical means to implement this idea. Drawing of wind wagon, i.e. wagons carrying a windmill that operates the wheels through a number of gear wheels, were common in the 'theaters of machines' i.e. books containing the sketches of a number of actual and fantastic machines. Likely the first of such sketches was drawn by Guido da Vigevano in 1328; others can be found in the books by Roberto Valturio and by Mariano Jacopo, said Taccola, from the first half of the fifteenth century. These machines were never built, or at least, could not work as expected.

The use of sails could yield better results, and in 1599 Simon Stevin built a sail wagon for Maurice of Orange. It could carry 28 persons, and is said to have reached a speed of 12 km/h. It did not have however practical applications. Other attempts were made using clockwork mechanisms, and the German clock-maker Hans Hautsch built a wagon powered by steel springs that was said to be able to travel at about 1.5 km/h, but its range is not known.

In these applications the wheel had not only the usual task of supporting the vehicle, but also that of producing the traction needed for motion. A wagon with a fully developed steering and driving mechanism can be found in some drawings by Francesco di Giorgio Martini, who worked in the second half of the fifteenth century. The vehicle has four driving and steering wheels, powered by devices similar to the ones used in capstans, operated by humans or animals. It is then not an automotive vehicle, but incorporates devices that will be later essential to build self propelled vehicles.

In order to build a truly successful automotive vehicle it was necessary to wait until a viable thermal engine, with a power/mass ratio high enough to operate a vehicle able to transport the engine plus a certain payload, was available. This idea was around since at least the seventeenth century: For instance in 1681 the missionary F. Verbist reported that a steam vehicle (likely a reduced scale model) had been built in China and a sketch in a work of Isaac Newton shows a vehicle propelled by the reaction of a steam jet. It is, however, likely that the drawing is only a sketch to show the reaction principle and that Newton never thought seriously to that application.

In spite of these early ideas, it was only at the end of the eighteenth century that a suitable thermal engine was available, but a further century had to pass before the early attempts could produce vehicles that could find practical applications.

As stated in the preface, the early motor vehicles were built following a wide variety of technical solutions for almost all the functions that an automotive vehicle had to incorporate. About 30 years were needed for a few standard layouts to emerge and for the motor car to reach its maturity. For example, if we consider the function

of transmitting the motion from the engine to the wheels, that will be described in details in a specific section, cars of the end of the nineteenth century used:

- Belt transmissions.
- Cylindrical gear gearboxes.
- Bevel gears gearboxes.
- Continuously variable transmissions based on friction wheels.

In the 1920s the variety of gearboxes virtually reduced to the cylindrical gears type, with dog clutches or sliding trains, all of them with a friction clutch as a start-up device; in the 1940s the first synchronizers appeared, developed by Mercedes, Porsche and Borg Warner.

Presently, differences in gearboxes are virtually inexistent, if we neglect differences due to the different powertrain lay-out. We can thus conclude that a manual gearbox now is a mature product.

The same cannot be said for automatic gearboxes, at least for Europe, where such a component is at its initial development stage. The attention of the market to purchase and running costs and the interest of customers in the fun of manually shifting gears worked against their diffusion till some years ago. The present situation of congested traffic is shifting major shares of manual transmissions in favour of automatic transmissions, significantly improved by the application of electronics. A different environment has shifted the balance between costs and benefits.

Present European automatic transmissions still show many different solutions:

- Planetary gears with multi-disc clutches of many different families.
- Conventional gears with a clutch for each gear.
- Conventional gears with a clutch for shaft (dual clutch gearbox).
- Continuously variable gearboxes with variable geometry.

In a near future some of them could prevail and bring the synchromesh manual gearbox to extinction. Many other similar examples will be shown in the next sections addressed to body system, chassis systems and powertrains.

At the end of the 1920s the general architecture of cars was standardized but the 1929 crisis marked a setback also for the automotive industry, particularly in the United States.

After World War Two the car industry restarted with a new pace, and the aim of a car for each family seemed reasonable, first in the United States and then in Europe. This goal was reached and, in the more developed countries, many families had soon more than one car. Technological development went on at a lower pace and by the middle of the 1960s the automotive industry seemed mature and little innovation seemed to be in sight.

As often happens, when a technology seems to be mature, new requirements and new problems forced the automotive industry to change deeply. The first problem that had to be tackled was safety. A new consciousness of the social cost of car accidents and new laws extending the responsibility of manufacturers forced to look at safety issues in a different way. New definitions of active and passive safety and new regulations forced deep changes in the design of all car subsystems, particularly

of the chassis and the body, and new vehicles, defined Experimental Safety Vehicles (ESV), were presented at all car shows. While ESVs soon faded away, and rightly since they were true monsters, massive and fuel-hungry, the work done on safety issues lead in a few years to vehicles which were much safer than those built in the past.

Before the research work on safety could produce any effect, a new issue came out, and the focus shifted on the pollution caused by the use of motor vehicles, particularly in urban environment. New regulations on emissions, more and more restrictive, were, and still are being, enforced in all countries.

While the automotive industries were dealing with the two mentioned problems, safety and pollution, a third problem, namely the sudden increase of the cost of oil, came out. The new imperative was soon to decrease fuel consumption, an imperative often in contrast with the attempts to satisfy the other two mentioned requirements—it is enough to mention the high fuel consumption of the ESVs.

Under the pressing requirements caused by the changed scenario in which the automotive industry had to operate, a technology that was assumed to be mature had to innovate deeply. By the end of the millennium deep changes had reached the average customer, and the long wave of change is far from being over. For sure the new design methods allowed by the introduction of computers first in the design and then in the production of vehicles helped. Computer simulation and virtual prototyping allowed solution at the design stage of many problems that before could be tackled only by costly and tiresome experimentation and automation allowed to produce motor vehicles of increasing complexity, as required by the new needs, at costs still compatible with the possibilities of consumers.

Computers and generally information technology did not only change the way cars are designed and built, but entered the vehicles themselves. In present motor vehicles many functions that before were performed by mechanical systems or by the driver are now entrusted to microprocessor-based control system, and this has changed, and likely will change in the future, the way motor vehicles operate and are used.

A chronology of the most important technical events that affected car evolution is presented as a closure to this introduction.

3500 B.C.: Introduction of the wheel for ground vehicles.
2000 B.C.: Introduction of the spoked wheel.
1328: First drawing of a wind wagon by Guido da Vigevano.
1595: First vehicle suspended on springs, described by Fausto Venanzio.
1599: Simon Stevin builds a sail wagon.
1630: First description of tractive wheels (operated by humans on board) for a vehicle (they had already been used on war engines).
1673: First idea about an internal combustion engine operated by an explosive charge according to the Dutch physicist C. Huygens.
1690: D. Papin develops an idea about a steam engine suitable to move a motor carriage.
1769: N. J. Cugnot builds up a steam carriage with a pressure vessel and two cylinders acting on the front single wheel axle.

1802: R. Trevithick builds his first steam coach, that opens the era of the steam coaches in England.
1803: R. Trevithick invents a steam engine on rails; an horizontal cylinder moves the rear axle with a rod and crank mechanism.
1807: I. De Rivaz builds a vehicle with an atmospheric internal combustion engine, working on hydrogen and electrical spark plug.
1817: Ackermann, English agent of the German inventor G. Längensberger, files a patent about steering of four wheels vehicles in cinematically correct conditions.
1822 : The first commercial service of steam coaches (London–Birmingham) is started.
1823 : First electric car made by Jacobi.
1824 : S. Carnot publishes his treatise on thermal engines where he defines an operating cycle and the related thermal efficiency.
1828 : F. Pecqueur invents and files a patent on a differential to be applied on a steam carriage.
1839 : C. Goodyear invents the vulcanization process, to improve the mechanical properties of rubber.
1845 : R. W. Thompson files a patent about a tire, to be applied to a horse carriage to reduce the traction force and improve comfort.
1846 : Thomas Hancock builds a solid rubber tire to be added to the steel tires of the wheels of coaches.
1856 : E. Barsanti and F. Matteucci file a patent about the first combustion engine working automatically.
1860 : E. Lenoir introduces a double acting gas internal combustion engine, without compression; it is the first to be produced industrially.
1862 : A. Beau De Rochas gives a description of a four cycle internal combustion engine with compression.
1865 : The Red flag law requiring the presence of a man walking in front of the motor vehicles with a red flag and a speed limit of 6.4 km/h is passed in England. It ended the era of the steam coaches.
1867 : N. A. Otto and E. Langen start production of an atmospheric internal combustion engine.
1878 : C. Jeantaud, a French car manufacturer, develops a link mechanism to obtain Ackermann conditions in practice.
1880 : A. De Bollée builds the steam cars Obeissante, Mancelle and Rapide; the last one, a 6 places car, is capable of a speed of 60 km/h.
1884 : The patents of N. A. Otto are cancelled, because of prior claims by A. Beau De Rochas. From this date internal combustion engines are free of any licence burden.
1884 : G. Daimler develops the first four stroke single cylinder internal combustion engine for vehicles, featuring 0.5 HP (0.35 kW).
1886 : K. Benz develops the first car driven by an internal combustion single cylinder engine featuring 0.8 HP (0.6 kW).
1886 : First Daimler car.
1887 : R. A. Bosch files a patent about electrical magneto ignition.
1888 : J. B. Dunlop files a patent about bicycle tires, but the patent is invalidated in 1890 because of Thompson's priorities.
1890 : Panhard and Levassor presents the first car with front engine and rear driving axle with an engine built under Daimler's licence.
1891 : Peugeot introduces his car, with Panhard and Levassor engine. Panhard and Levassor and Peugeot are first in the world to produce cars with industrial processes.
1892 : R. Diesel files a patent about a constant pressure internal combustion cycle.
1896 : E. and A. Michelin apply a pneumatic tire to a car.
1899 : L. Renault develops the first direct drive gearbox, a shaft transmission with universal joint and, immediately after, the first sedan car.
1899 : The French government enforces the first Highway code with a maximum speed of 30 km/h in the country and 20 km/h in the town; the driving license is also introduced.
1905 : De Dion-Bouton develops the first single disc friction clutch.
1910 : Isotta-Fraschini introduces the first four-wheel braking system.

1912 : Cadillac introduces the first electric starter and the breaker ignition according to the ideas of C. Kettering.
1920 : Artz in Germany develops the first stamping press for steel sheets.
1921 : Duesemberg develops the first hydraulic braking system with Lockheed components.
1922 : Lancia develops the first unitized body.
1927 : Budd and Dodge develop the first electrical spot welding process.
1927 : Bosch develops the first high pressure diesel injection pump.
1928 : Packard applies the first synchromesh gearbox.
1933 : Lancia develops the first unitized body for a sedan car.
1936 : Mercedes introduces the first car with a prechamber diesel engine.
1939 : Packard applies the first air conditioning system.
1947 : Goodrich invents the tubeless tire.
1948 : Buick applies the first automatic transmission with planetary gears and torque converter.
1949 : Michelin introduces the first radial tire.
1952 : General Motors applies the first hydraulic power steering system.
1954 : Mercedes develops the first direct gasoline injection engine for a car.
1954 : Ford and Chevrolet apply the first pneumatic power brake system.
1955 : Citroën applies the first disk brake to a car.
1959 : Volvo applies the first three point safety belt.
1960 : The first emission regulations are presented by Senator E. Muskie in the USA.
1960 : Bosch develops the first oxygen sensor.
1960: Bosch introduces the first diesel rotary pump.
1962 : Ford introduces the first rack-and-pinion steering box.
1967 : Bosch introduces the first electronic gasoline injection system.
1973 : Engelhard develops the first three way catalist for exhaust gas aftertreatment.
1974 : Bosch introduces the first air flow meter for gasoline injection systems.
1978 : Bosch introduces the first ABS system.
1988 : FIAT applies the first direct injection diesel engine to a car.
1990 : Pioneeer introduces the first navigation system based on GPS technology system.
1995 : Bosch introduces the first vehicle dynamic control electronic system system.
1997 : FIAT introduces the first diesel common rail injection system in a car engine.